R&M 2000 VARIABILITY REDUCTION PROCESS

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THE PROCESS

Improving combat capability is a major Air Force objective. This is becoming increasingly difficult in the face of constrained manpower and fiscal resources. However, there is a solution. Substantial increases in combat capability are achievable through more reliable and maintainable weapon systems. Such systems are able to complete more missions with less spares, support equipment, facilities and maintenance personnel.

Weapon systems fail for many reasons. Some components, like tires, wear out. But most systems fail because of poor design, the use of defective parts and materials, or poor workmanship. The cause of these failures is *variability* in the design and manufacturing processes. The problem variability presents is that it exists in nearly all processes and it results in marginal or non-conforming products. The variability comes from the fact that conditions under which these items are produced change. Variability reflects the differences in raw material, machines, their operators and the manufacturing conditions. When process variation Increases, the product's physical properties or functional performance can degrade, and the number of product defects increases. The significance variation has on a product's reliability and quality depends on the criticality of the manufacturing process and part characteristics.

There are two ways to reduce variability. Traditionally, the approach has been to tighten design tolerances and increase inspections. Costs climb as scrap and rework increase, and productivity drops. Inspections and tighter tolerances only treat the symptoms and do not resolve the actual problem.

The preferred method is to reduce the variabifitybyimproving the process. This can be done by eliminating the causes of variation through statistical techniques, and by developing more robust products which are insensitive to the causes of variation. The methods of reducing variability is aptly named the Variability Reduction Process (VRP).

VRP is a proven set of practices and technologies which yield more reliable and nearly defect-free products at lower cost. It is a structured, disciplined design and manufacturing approach aimed at meeting customer expectations and improving the development and manufacturing process while minimizing acquisition time and cost (Figure 1).

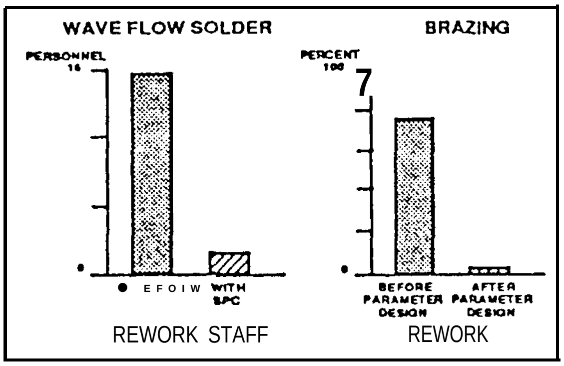


Figure 1. Process Improvements from VRP.

The objectives of VRP are to design robust products which are insensitive to the causes of failure; to achieve capable manufacturing processes that produce nearly defect-free products: and to adopt the managerial attitude of continuously improving all processes. The basic tools are teamwork, statistical process control (SPC), loss function, design of experiment (DOE), parameter design and quality function deployment (QFD). VRP must span all of engineering, manufacturing and management, and include the suppliers (Figure 2).

PURPOSE: MEET CUSTOMER EXPECTATIONS IN MINIMUM TIME, AT LOWEST COST			
OBJECTIVES	ROBUST DESIGNS	CAPABLE PROCESSES	CONTINUOUS IMPROVEMENT
PRIMARY RESPONSIBILITY	ENGINEERS	MANUFACTURING	MANAGEMENT
TEAMS	INTERDISCIPLINARY	IMPROVEMENT	MULTI-FUNCTIONAL
TOOLS / TECHNOLOGIES	QFD / DOE / PARAMETER DESIGN	DOE / SPC	LOSS FUNCTION

Figure 2. The Elements of VRP.

CAPABLE MANUFACTURING PROCESSES

Capable manufacturing processes can only be achieved when the critical parameters are known, and the causes of variation are eliminated or minimized. For most processes, SPC is highly effective (Figure 3). It allows the operator to observe the process and distinguish between patterns of random and abnormal variation. It assists the operator in making timely decisions such as adjusting or shutting down the process before defects are produced. When combined with other statistical tools and problem solving techniques (Figure 4), the worker can isolate and remove the causes of abnormal variations.

When the abnormal variations are removed from the process, the process is said to be under statistical control. In many processes, this will not be sufficient. me random variations alone can result in defective products, and their causes should be identified and removed until the process is capable of producing near defect-free products. However, causes of random variation are more difficult to identify, are usually systemic and normally require management action to remove.

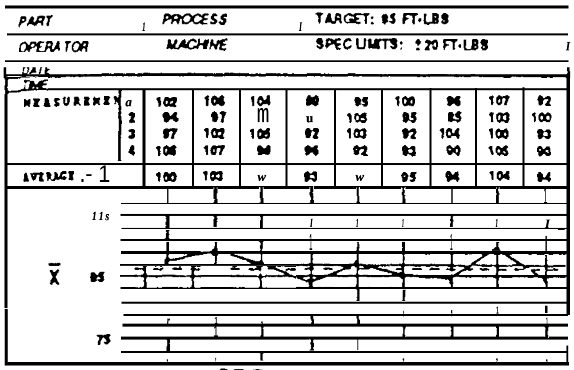


Figure 3. *SPC Control Chart*

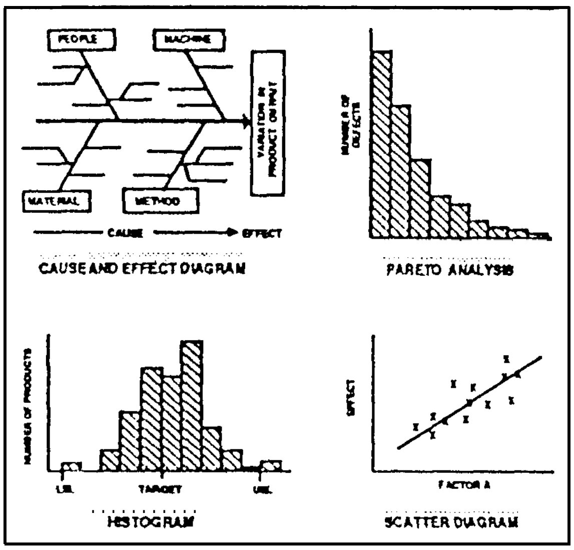


figure 4. *Took Workers Can Use to Identify the Causes of Variation.*

The difference between VRP and traditional methods of quality control is that improvements in quality are achieved through improvements in the manufacturing processes. No longer is better quality to be achieved through tightening specifications and more inspections. In the case of SPC, the manufacturing processes are improved by eliminating the causes of variability. Usually, the process can be centered around the design target and variation reduced well within the specifications (Figure 5).

When implemented correctly, the results can be impressive. For Parlex Nevada Inc, a circuit card manufacturer, SPC was used to cut scrap cost by 90 percent in one year, and changed the company's losses into profits. Boeing used SPC to resolve a rivet flushness problem on the nose section of the 737 aircraft. The improvements saved a half-million dollars a year.

A more powerful method of resolving difficult or complex industrial problems is the statistical design of experiments (DOE). DOE methods have been around for 60 years and have been extensively used by the agricultural, pharmaceutical and chemical industries to advance their products. These techniques can greatly accelerate the rate of improving product designs and manufacturing processes. Such statistical experiments will aid the engineer in identifying the critical parameters for SPC, isolating the causes of variation, and improving the product's technical or operational characteristics.

DOE works by measuring the effects that different inputs have on a process. This is done by identifying a prospective set of Input factors, varying

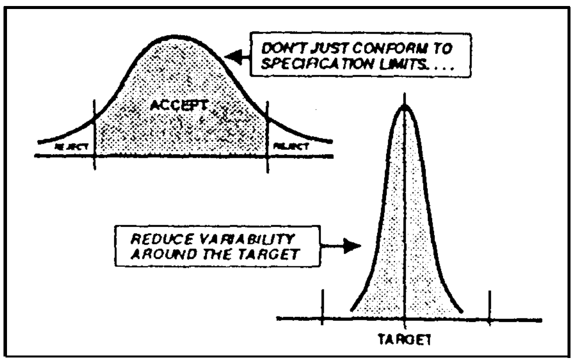


Figure 5. Design and Build to Target Values, Not Specification Limits.

the inputs overa series of experiments, collecting the data and analyzing the results. An input may be varied over a range of values such as can be done with an oven's curing temperature or conditionally, such as the decision to add or withhold a curing additive. The methods, whether they employ a full-factor, fractional-factor, orthogonal array or surface response technique, use a statistical approach that ensures accuracy and validity.

Well-planned experiments can have dramatic results. For example, a government-owned-company -operated (GOCO) munitions plant had a serious problem in producing the ADAM mine. Although SPC was in use and 120f 13 processes were within their tolerances, 19 out of 25 lots were rejected. Aerojet Ordinance, the plant operator, decided to appfy a Taguchi experiment to identify the critical parameters. They selected the 13 parameters used in the SPC program and tested parameters at three different levels. Only 27 experiments were conducted, firing 6 rounds each. The results were profound. Four parameters were found to be critical, and when set at their best levels, the process produced good lots without any rejects. The other nine parameters were less important and their tolerances can be relaxed. Results: production schedule met while achieving significant cost savings.

ROBUST DESIGNS

Having a capable manufacturing process is not enough. It may not be economical to remove or *control* some of the causes of variation. Therefore, it is necessary to develop robust manufacturing processes which are insensitive 10 the manufacturing conditions, materials, machines and operators. In most cases, *the* greatest *improvements come from robust designs. These* improvements are achieved through parameter design, a technique of selecting the optimum conditions (i.e. determining the ideal parameter settings) that minimize the variability without removing the causes of variation.

During parameter design, a set of parameters is identified to enhance the product, and a series of experiments is conducted to observe the effects of the parameters on the desired part characteristics. The results could identify new parameter settings that improve the product and increase yield. For example, the problem an engineer may want to solve is the variability of ceramic parts. The source of variation is the uneven temperatures in the kiln. Because modifying the kiln is too expensive, the engineer conducts several experiments to identify a way to minimize the effects of the uneven temperature. For the experiment, he selects as parameters the amounts of the ingredients, their textures, blending procedures and firing temperatures. For validity, the engineer should use DOE procedures for conducting the experiment. An orthogonal array maybe used to minimize experimental time and cost. The results will enable the engineer to fine new parameter settings that minimize the effects of uneven firing temperatures.

The problem with most design approaches is that parameter design is rarely done. Most engineers focus on the system design to develop the product, and immediately transition to tolerance design to establish the specification limits. Often, the results is a inferior product which is sensitive to variations in the manufacturing process. Parameter design should be done before tolerance design.

Parameter design can also be used to design and produce a more robust product that will perform better over a wider range of operating conditions and environments. It can be used to enhance a desired customer's need such as a smooth automobile ride, or to enhance an engineering requirement such as to lower the susceptibility of corrosion.

The success of parameter design and SPC hinge on the engineers' understanding of the customers' needs. Quality Function Deployment (QFD)

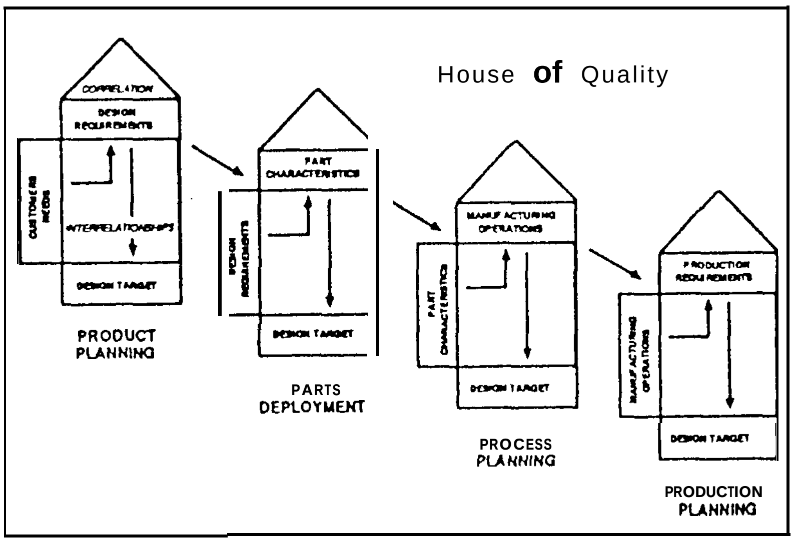


Figure 6. Quality Function Deployment.

is a systematic approach for developing and translating the customers needs into the critical part characteristics and production requirements. The QFD requirements matrices are designed to minimize the chance of starting the design process with incomplete or erroneous requirements. They provide a methodology which assures an orderly translation of the customers' requirements throughout the product development process (Figure *6).*

The basic approach used in QFD is conceptually similar to the practice employed by most companies. The difference lies in its structure. It compels the different disciplines and departments to communicate. QFD starts by defining the customers' requirements in the customers' terminology and translates these requirements into engineering requirements. These engineering requirements become the product characteristics which should be measurable and given target values. If property executed, the product should fulfill the expectations of the customer.

The other matrices translate the engineering requirements into part characteristics, required manufacturing operations, and production requirements. Each matrix identifies the design targets, interrelationships and priorities. The end result should be a set of operating procedures which the factory can follow to consistently produce the critical pari characteristics.

The design environment best suited to produce robust products is concurrent engineering (also referred to as simultaneous engineering). Concurrent engineering addresses all the customer, design and manufacturing issues up-front starling with concept exploration. The process employs good design practices, interdisciplinary learns and a structured requirements process, such as QFD, to concurrently develop the product and manufacturing processes. Its practice encourages communication between the design, product and production engineers. Concurrent engineering replaces the typical "sequential" approach 10 product design, which is more costly and time consuming. The effects concurrent engineering can have maybe summed up by the following example. Using sequential engineering practices, the Allison Transmission Division estimated in 1982 it would cost $100 million in capital investment and $75,000 per unit to replace the transmission *in* the M-113 Armored Personnel Carrier. In 1987, using concurrent engineering, Allison's estimate dropped to $20 million for capital investment and $50,000 per unit (Figure 7).

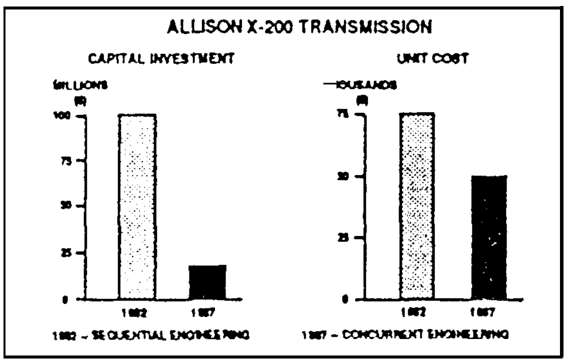


Figure 7. Concurrent Engineering.

CONTINUOUS IMPROVEMENT

For VRP to succeed, management from the top down must adopt new attitudes about reliability and qualify, and must become *direct/y involved* in continuously improving the design and manufacturing processes. They must implement programs to foster improvement, teardown the barriers that inhibit change, instill teamwork, establish goals for improvement, and provide education and training for successful implementation.

Management's primary objective should be to satisfy the customer and serve the customer's needs if a company is to stay in business and make a profit. Reliability and quality must come first — not profit. If done smartly, reliability and quality will reduce cost and increase profit. For example, Hewlett-Packard's Yokogawa plant implemented many of the VRP techniques and, after eight years, they achieved 240 percent increase in profit, 120 percent increase in productivity, 19 percent increase in market share, 79 percent decrease in failure rate, and 42 percent decrease in manufacturing costs.

Management must become *process-oriented* and stimulate efforts to improve the way employees do the job. Teamwork is the foundation for continuous improvement. An important parl of team building is the assignment of people to multi-functional management teams, interdisciplinary design teams and process improvement teams. Everyone should be involved in process improvement.

Management should implement programs to foster continuous improvement, use education to change attitudes and provide training. Change will be gradual and will require a brig-term outlook. In Japan, most of the small improvements come from the workers' suggestion system called *Kaizen Teian.* Kawasaki Heavy Industries Aircraft Works has one of the more impressive programs. In 1987, each employee submitted an average of 229 suggestions and 92 percent were adopled. Savings were estimated al $35 million. At a Texas instruments plant, [hey introduced an enhancement program, and over the past five years, the program has reduced defects by 2,300 percent (figure 8).

Management must take responsibility for process ‘improvement while giving the workers the responsibility of maintaining the process. Without the ability 10 maintain the existing process, there can be no improvement. This means management must give the worker ownership of his processes and allow the worker 10 improve or slop the process as necessary. In many progressive companies, workers are involved in the development of their own operating procedures, and in some cases, they write their procedures.

Management must change the accounting procedures. The notion that loss only occurs when the product is outside the specification limits is obsolete. Loss includes not only the cost of scrap and rework, but also the cost of warranties, excess inventory and capital investment, customer dissatisfaction, and eventual loss of market share. The traditional go/no-go approach to quality should be replaced with a powerful monetary loss function to better account for loss (Figure 9). A quadratic loss function allows management to better assess the true cost of production processes and the benefits' derived from process improvements (Figure 10). Most important, the loss function supports continu-

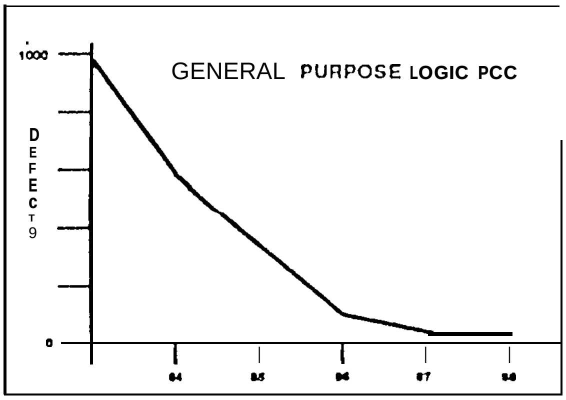


Figure 8. *Continuous* Improvement.

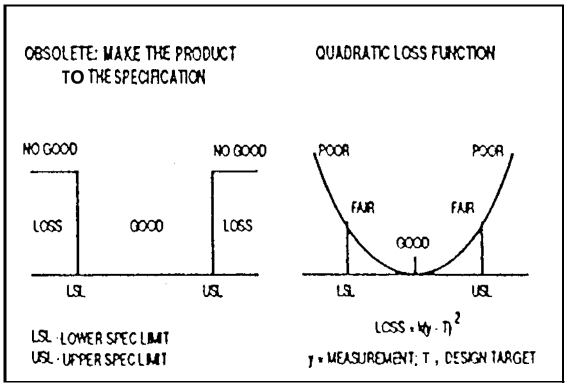
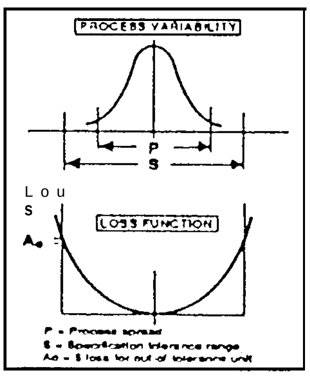


Figure 9. Quality Loss Functions.



	A	B	C	
PROCESS CAPABILITY INDEX (Cp)	PROCESS SPREAD RATIO P/S	AVERAGE $ LOSS/UNIT /DOLLAR (COLUMN A)²	AVERAGE $ LOSS/UNIT COLUMN B x Ao	AVERAGE $ LOSS FOR RUN COLUMN C x N
1.00	1.0	.111	$22.20	$22,200
1.11	0.9	.090		
1.25	0.8	.071		
1.43	0.7	.054	$10.80	$10,800
1.67	0.6	.040		
2.00	0.5	.028		
2.50	0.4	.018		
3.33	0.3	.010		
5.00	0.2	.004		
10.00	a l	m l		

COST AVOIDANCE: $11,400

ASSUMPTIONS
- (±) TOLERANCE EQUAL
- PROCESS IS CENTERED
- PROCESS IS SYMMETRICAL
- QUADRATIC LOSS FUNCTION
- "RATIONALLY" SET SPECIFICATIONS

EXAMPLE SHOWN
- ESTIMATE SAVINGS OF IMPROVING PROCESS FROM 1.0 TO 0.7
- DOLLAR LOSS AT EITHER SPEC LIMIT IS Ao = $200
- NUMBER OF UNITS TO BE PRODUCED IS N = 1000

Figure 10. Table for Evaluating the Benefits from Process Improvement.

ous process improvement because minimizing the loss equates to reducing the variability around the target.

IMPLEMENTATION

The adoption of VRP begins with the conviction that change is necessary and beneficial. Implementation is an evolutionary process. VRP may start out in a single product line at one factory with a single group of suppliers. But it must be grown with the fong-range goal that it will encompass the entire enterprise. The Air Force strategy for VRP is to encourage defense contractors and suppliers to (1) foster top-level commitment to VRP, (2) involve all levels, departments and vendors, (3) apply the VRP in a systematic approach, and (4) create a culture of continuous process improvement. Within the Air Force, the Vice Chief of Staff has directed all commands involved in weapon system acquisition and support to implement VRP by 1993. The Air Force acquisition regulations have been rewritten to incorporate VRP in the acquisition process. VRP will be an essential part of Air Force's Total Quality Management program (Figure 11).

INCREASING COMPLEXITY	TQM TOOLS	R&M 2000 VRP: CAPABLE PROCESSES	R&M 2000 VRP: ROBUST DESIGN
	TEAM WORK	X	X
	SPC	X	
	LOSS FUNCTION	X	X
	DESIGN OF EXPERIMENTS	X	X
	PARAMETER DESIGN		X
	HOUSE OF QUALITY (QFD)		X

Figure 11. TQM / VRP Relationhhip

SUMMARY

The Variability Reduction Process makes two seemingly contradictory goals compatible: to produce highly reliable and maintainable weapon systems while reducing development time and costs. The method is to design robust systems, produce them with capable manufacturing processes, and achieve continuous improvement.

VRP provides a win-win situation. The Air Force obtains more combat capability with the available dollars. Industry is able to satisfy their customers, improve productively and lower costs.

REFERENCES

Statistical *Process Control:*

E. L. Grant and R. S. Leavenworth, Statistical Process Control (5th ed), McGraw Hill, New York, 1979.

J. S. Oakl Statistical Process Control, Wiley, New York, 1966.

D. J. Wheeler and D. S. Chambers, Understanding Statistical Process Control, Statistical Process Controls, Inc., Knoxville, TN, 1966.

Design of Experiment/Parameter Design:

G. C. P. Box. W. G. Hunter and J. S. Huntar, Statistics for Experimenters, Wiley, New York, 1978.

G. C. P. Sax, S. Bisgaard and C. Fung, 'An Explanation and Critique of Taguchi's Contribution to Quality Engineering, - Quality and Reliability Engineering International, Vol. 4, 123-131, (1966).

C. Daniel, Applications of Statistics to Industrial Experimentation, Wiley, New York. 1976.

R. V. Hogg and J. Ledolter, Engineering Statistics, MacMillan Publishing, New York, 1967.

S. R. Schmidt and R. G. Launy, Understanding Industrial Design of Experiments, Department of Ma thematical Sciences, USAF Academy, CO, (pending publication, Summer 19S9).

G. Taguchi and Y. Wu, Introduction to Off-Line Quality Control, Central Japan Quality Control Association, Nagoya, Japan. 1980.

G. Taguchi, System of Experimental Desian — Engineering Methods to Optimize Quality and Minimize Costs, UNIPUB/Kraus International Publications, White Plains, NY, 1987.

Quality Function Deployment:

J. R. Hauser and D. Clausing, "The House of Quality," Harvard Business Review, (May-June 1968)

B. King, Better Designs in Half the Time: Implementing QFD Quality Function Deployment in America, GOAL/QPC, Methuen, MA, 1987.

L P. Sullivan, "Quality Function Deployment," Quality Progress, (June 19S6), pp 39-50.

Concurrent (Simultaneous) Engineering:

R. I Winner, J. P. Pennell, H. E. Bertrand and M. Slusarczuk, The Role of Concurrent Engineering in Weapon System Acquisition (IDA Report R-338), Institute for Defense Analyses, Alexandria VA, 1968.

Continuous *Improvement:*

M. Imai, Kaizen, Random House Business Division, New York, 1986,

w. w. Scherkenbach, The Deming Route to Quality and Productivity — Road Maps and Roadblocks, Mercury Press/ Fairchild Publications, Rockville, MD, 1966.

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